6.1 Scope

Limit States Design shall be used for foundations, embankments, slopes and geotechnical systems.

6.1 Definitions

Add the following:

Embankment – earth slopes with or without a foundation unit.

6.4.1 Limit States

Serviceability Limit State SLS Combination 1, given in Table 3.1, shall be used for global (overall) stability of embankments, slopes and fills.

6.7 Geotechnical report

6.7.3 Design information

Replace the last sentence and replace with the following:

Signing and sealing of the Geotechnical report shall be in accordance with Association of Professional Engineers and Geoscientists in British Columbia (APEGBC) requirements.

6.9 Geotechnical Resistance

6.9.1 General

Add the following to this section:

The following benchmarks in Table 6.2a provide guidance for determining the Degree of Understanding for use of Table 6.2 for deep foundations:

Table 6.2a
Benchmarks for Degree of Understanding for Deep Foundations

Test Method/ Model	**Degree of Understanding**		
Compression	**Low**	**Typical**	**High**
Static Analysis	• Design based on SPT blow counts and soil sample descriptions from boreholes representative of conditions at project site.	• Design based on SPT blow counts and soil sample descriptions from boreholes representative of conditions at each bridge pier and abutment.	• Design based on CPT data representative of conditions at each bridge pier and abutment. **<u>OR</u>** • Design based on BPT data representative of conditions at each bridge pier and abutment, and • Measure bounce chamber pressure and consider BPT friction.
Static Test	• Design based on, a single test pile for bridge pier as per ASTM D1143., and • Results extrapolated to other bridge piers by consideration of borehole or CPT data, and • Test pile size and toe condition may not be the same as production piles.	• Design based on a single test pile for bridge pier as per ASTM D1143, and • Test pile instrumented with at least a tell-tale. Force applied at pile head above ground, and • Test pile size shall be similar to the production pile, but toe condition shall be the same as production piles, and • Results extrapolated to other bridge piers by consideration of borehole or CPT data. **<u>OR</u>** • Design based on a single pile test with single level high capacity, sacrificial loading unit embedded in the foundation unit (O-Cells unless consented to by the Ministry) instrumented with force measurement, and • Test pile size shall be similar to the production pile, but boring method shall be the same as the production pile, and • Results extrapolated to other bridge piers by consideration of borehole or CPT data.	• Design based on a single test pile for bridge pier as per ASTM D1143, if bridge piers are separated less than 500 metres, and • Design based on two test piles for bridge pier as per ASTM D1143, if bridge piers are separated more than 500 metres, and • Test pile instrumented with at least toe tell-tale and strain gauges attached to pile at appropriate elevations. Force applied at pile head above ground, and • Test pile size shall be similar to the production pile, but toe condition shall be the same as production piles, and • Results extrapolated to other bridge piers by consideration of borehole or CPT data. **<u>OR</u>** • Design based on one test pile with two-level high capacity, sacrificial loading unit embedded in the foundation unit (O-Cells unless consented to by the Ministry) if bridge piers are separated less than 500 m, and • Design based on two test piles with two-level high capacity, sacrificial loading unit embedded in the

			foundation unit (O-Cells unless consented to by the Ministry) if bridge piers are separated more than 500 m , and • Test pile size shall be similar to the production pile, but boring method shall be the same as the production pile, and • Results extrapolated to other bridge piers by consideration of borehole or CPT data.
Dynamic Analysis	• Wave equation analysis (WEAP unless otherwise consented to by the Ministry) performed before construction for multiple driving systems **<u>OR</u>** • Wave equation analysis (WEAP unless otherwise consented to by the Ministry) performed using pile driving blow count data from previous installations at the site.	• Wave equation analysis (WEAP unless consented to by the Ministry) performed with pile driving blow count data on production piles for the full depth and known driving system.	• Wave equation analysis (WEAP unless consented to by the Ministry) performed using pile driving blow count data on production piles for full depth, damage observations and measured blow rate data for diesel hammer, or using known efficiency for a hydraulic hammer.
Dynamic Test	• Pile dynamic testing (PDA unless otherwise consented to by the Ministry) and dynamic analysis (CAPWAP unless consented to by the Ministry) conducted on an adjacent bridge pier or abutment used with pile driving blow count data obtained for the pile. **<u>OR</u>** • Design based on a single rapid load test on a pile for bridge pier or abutment as per ASTM D7383, and • Results extrapolated to other bridge piers and abutments by consideration of borehole or CPT data, and • Test pile size and toe condition may not be the same as production piles.	• Pile dynamic testing (PDA unless otherwise consented to by the Ministry) and dynamic analysis (CAPWAP unless otherwise consented to by the Ministry) conducted at each bridge pier and each abutment, and • blow count data for other piles at the same piers or abutments collected with a hammer having consistent driving energy.	• Pile dynamic testing (PDA unless otherwise consented to by the Ministry) and dynamic analysis (CAPWAP unless otherwise consented to by the Ministry) conducted at each bridge pier and each abutment, and • Have borehole or CPT data to define the ground conditions, and • Have consistent driving energy delivered from the driving system with measured blow rate data for diesel hammer, or using known efficiency for a hydraulic hammer.

Table 6.2a (continued)
Benchmarks for Degree of Understanding for Deep Foundations

Test Method/ Model	**Degree of Understanding**		
Tension	**Low**	**Typical**	**High**
Static Analysis	• Design based on SPT blow counts and soil sample descriptions from boreholes representative of conditions at project site.	• Design based on SPT blow counts and soil sample descriptions from boreholes representative of conditions at each bridge pier and abutment.	• Design based on CPT data representative of conditions at each bridge pier and abutment. **<u>OR</u>** • Design based on BPT data representative of conditions at each bridge pier and abutment, and • Measure bounce chamber pressure and consider BPT friction.
Static Testing	• Design based on a single test pile for bridge pier as per ASTM D1143, and • Results extrapolated to other bridge piers and abutments by consideration of borehole or CPT data, and • Test pile size and length shall be similar to the production piles.	• Design based on a single test pile for a bridge pier as per ASTM D1143, and • Test pile instrumented to measure toe and shaft capacity. Force applied at pile head above ground, and • Test pile size may not be the same as the production pile, but length shall be the same as production piles, and • Results extrapolated to other bridge piers by consideration of borehole or CPT data. **<u>OR</u>** • Design based on a single pile test with single level high capacity, sacrificial loading unit embedded in the foundation unit (O-Cells unless consented to by the Ministry) instrumented with force measurement, and • Test pile size and boring method should be the same as the production pile, and • Results extrapolated to other bridge piers by consideration of borehole or CPT data.	• Design based on a single test pile for bridge pier as per ASTM D3689, if bridge piers are separated less than 500 metres , and • Design based on two test piles for bridge pier as per ASTM D3689, if bridge piers are separated more than 500 metres, and • Test pile size and length same as production piles , and • Results extrapolated to other bridge piers by consideration of borehole or CPT data. **<u>OR</u>** • Design based on one test pile with two-level high capacity, sacrificial loading unit embedded in the foundation unit (O-Cells unless consented to by the Ministry) instrumented with force measurements, if bridge piers are separated less than 500 metres, and • Design based on two test piles with two-level high capacity, sacrificial loading unit embedded in the foundation unit (O-Cells unless consented to by the Ministry) instrumented with force measurements, if bridge piers are separated more than 500 metres, and • Test pile size and boring method should be the same as the production pile, and • Results extrapolated to other bridge piers by consideration of borehole or CPT data.

Note: Pile relaxation must be considered when using pile driving blow count or PDA data in certain very stiff soils or weak rock. Restrike data may be used if these conditions may be present.

Designs shall be based on information available at the time of design and higher resistance factors shall not be used based on the intent to do load testing or dynamic monitoring during construction. Higher resistance factors may be used based on data from load testing or dynamic monitoring that has been done to confirm resistance during construction.

In Table 6.2 under the column entitled "Application", replace "Embankment (fills)" with "Embankments".

The geotechnical resistance factors given in Table 6.2 for Global Stability of Embankments have been developed with the intent of achieving the following Factors of Safety (FOS) against global failure:

Table 6.2b
Resistance Factors, Consequence Factors and Factors of Safety for Global Stability of Embankments
(to be used in conjunction with Table 6.2)

Degree of Understanding	**Low**			**Typical**			**High**		
Resistance Factors for Global Stability – Permanent from S6-14	0.60			0.65			0.70		
Resistance Factors for Global Stability – Temporary from S6-14	0.70			0.75			0.80		
Consequence Factor from S6-14	High	Typical	Low	High	Typical	Low	High	Typical	Low
	0.90	1.00	1.15	0.90	1.00	1.15	0.90	1.00	1.15
FOS for Global Stability - Permanent	1.85	1.67	1.45	1.71	1.54	1.34	1.59	1.43	1.24
FOS for Global Stability - Temporary	1.59	1.43	1.24	1.48	1.33	1.16	1.39	1.25	1.09

The resistance and consequence factors (and the corresponding FOS values) in Table 6.2b shall be used with the load factors specified for the SLS Combination 1 in Table 3.1 of Chapter 3. This use is consistent with the methodology followed when computing the factor of safety on global stability of embankments using the currently available computer software programs.

The following benchmarks in Table 6.2c provide guidance for determining the Degree of Understanding for use of Table 6.2 for global stability of embankments:

Table 6.2c
Benchmarks for Degree of Understanding for Embankments

Degree of Understanding	Low Understanding	Typical Understanding	High Understanding
Global Stability	• Shear strength parameters established based on subsurface data from nearby sites and published correlations with the consistency/density of site soils supplemented with geological evidence, and • Stability of embankment evaluated using accepted computer software that incorporates the method of slices and limit equilibrium method of analysis, and • Embankment fill density and strength based on Ministry standard specification and published parameters.	• Shear strength parameters established based on a minimum of one borehole and published correlations with the consistency/density of site soils supplemented with geological evidence, and • Stability of embankment evaluated using accepted computer software that incorporates the method of slices and limit equilibrium method of analysis, and • FOS computed for an inferred groundwater profile, and • Embankment fill density and strength based on Ministry standard specifications and published parameters.	• Site-specific soil stratigraphy and consistency/density of soils established based on a minimum of two boreholes or 2 CPTs along the slope profile with laboratory testing to determine shear strength parameters, and • Groundwater profile established based on in-situ measurements, and • Low spatial variability of the subsurface soil conditions, and • Stability of embankment evaluated using accepted computer software that incorporates the method of slices and limit equilibrium method of analysis. Both force and moment equilibrium of slices shall be satisfied, and • Sensitivity of the computed FOS evaluated for differing groundwater profiles and anticipated variations in shear strength parameters, and • Embankment fill density and strength based on Ministry standard specifications and laboratory or in-situ testing. Fills placed with engineering supervision.

Commentary: *For low volume road bridges, modifications to the resistance factors may be considered with the consent of the Ministry.*

6.10 Shallow foundations

6.10.3 Pressure distribution

6.10.3.4 Eccentricity limit

Delete and replace with the following:

In the absence of detailed analysis, at the ultimate limit state for soil or rock, the eccentricity of the resultant of the factored loads at the ULS acting on the foundation, as shown in Figure 6.4, shall not exceed 0.30 times the dimension of the footing in the direction of eccentricity being considered for non-seismic load combinations, nor 0.40 times the dimension of the footing in the direction of eccentricity being considered for seismic load combinations.

Commentary: *This seismic requirement is in the Code Commentary. A study of some typical representative abutment and retaining wall configurations with typical bridge loading indicates that the Eccentricity Limits approach yields wall geometry requirements reasonably close to the traditional Working Stress design approach requiring a Safety Factor of 2.0 against overturning.*

6.15 Mechanically stabilized earth (MSE) structures

6.15.2 Design

6.15.2.1 General

Add the following to this section:

The requirements of the AASHTO LRFD Bridge Design Specifications (7th Edition, 2014) including interim revisions and FHWA-NHI-10-024 and -025 shall be used for items not covered in this Supplement or S6-14.

The maximum height for MSE walls using extensible soil reinforcing shall be 9 m. The maximum height of MSE walls using inextensible soil reinforcing shall be 12 m.

Inextensible soil reinforcement shall be steel. Extensible reinforcement shall be geogrid.

Only MSE Wall systems listed in the Ministry Recognized Products List may be used. MSE Walls shall meet all requirements given in the Recognized Products List.

Wire used in wire facing or soil reinforcing components of all MSE walls shall be galvanized and shall have a minimum thickness determined based on a 100 year design and corrosion-resistance durability requirements.

MSE walls in seismic performance category 2 and 3 must have anchored connections of the facing to the soil reinforcing that do not rely on friction.

Surface drainage and drainage of the backfill material and all reinforced zones shall be addressed in the design of the walls and details shall be shown on the Plans.

Two stage MSE walls shall only be used where consented to by the Ministry. The designer shall liaise with MSE wall suppliers to confirm wall system details prior to tendering. Only wall systems that meet the project specific criteria shall be shown on the Plans. Two stage MSE walls shall be constructed so that there is no void space between the initial stage 1 wall and the final stage 2 facing after construction.

a. ***Mechanically Stabilized Earth (MSE) Walls at Bridge Abutments and the associated Abutment Wing Walls***

Inextensible soil reinforcing shall be used. Geogrid extensible soil reinforcing shall only be used with consent of the Ministry based on a project specific evaluation.

The walls shall have precast reinforced concrete facing panels.

A reinforced concrete coping shall be used along the top of the walls.

Any portion of an MSE wall within a horizontal distance away from an abutment footing or pile cap equal to the height of the abutment wall shall also be considered as an abutment wall.

The minimum soil reinforcement length for walls shall be 70% of the distance from the top of the leveling pad to the bridge road surface. The reinforcement length shall be uniform throughout the entire height of the wall.

Geotechnical design, including global stability and subsurface liquefaction may require longer reinforcement than specified above.

b. ***Other Mechanically Stabilized Earth (MSE) Walls***

Inextensible or geogrid extensible soil reinforcing may be used.

Non-geogrid extensible soil reinforcing may only be used with the consent of the Ministry based on a project specific evaluation.

Uneven reinforcing lengths may be used when intact rock must be removed to accommodate the soil reinforcing.

MSE walls with wire mesh facing, dry cast concrete block facing, or rock stack facing shall only be used with consent from the Ministry.

Wire mesh facing shall only be used in Ministry Service Areas 1,2,3,4, 6 and 27 unless otherwise Approved. The design shall include provisions to ensure long term durability for the wire facing when exposed to spray or surface runoff containing de-icing chemicals.

Commentary for MSE walls:

Corrosion of wire faced MSE walls has occurred prematurely on Ministry walls. Wire faced walls need to be carefully designed for site specific environment and exposure conditions. Exposure to drainage, runoff and spray containing de-icing salts requires a corrosion evaluation during the design phase. The Service Areas listed above where wire faced walls may be considered have been chosen since they are areas where these facings have not been reported to have premature corrosion in service and where the walls are subject to rain that can help remove de-icing chemicals from the facing. Even in these listed Service Areas careful consideration of the site specific corrosion conditions is needed to verify the appropriateness of the use of wire faced walls.

The designer needs to consider the extent of quality control and quality assurance testing for the soil reinforcement for the specified walls systems and add these requirements to the Plans.

Add the following Clause:

6.18 Lightweight fills

All lightweight fills shall be adequately protected in terms of wheel loads, ground water, road salts, weather and fire resistance, flotation under flood conditions and fuel spills.

Where walls are used to contain flammable lightweight fills, the walls shall provide a 2-hour fire rating.

Any Foundation system or landscaping above the lightweight fills shall be designed such that the protective membrane covers for the lightweight fill shall not be compromised.

Flotation forces corresponding to inundation of the fill to the 200-year flood level shall be addressed in the design of lightweight fills, regardless of any flood protection provided for the area in which the fill is to be constructed.

Expanded Polystyrene (EPS) lightweight fills shall meet the following requirements:

- EPS shall be supplied in the form of blocks. It shall be classified as to surface burning characteristics in accordance with CAN/ULC-S102.2-03-EN, having a flame spread rating not greater than 500.
- The minimum compressive strength, measured in accordance with ASTM D1621 shall be 125 kPa at a strain of not more than 5%.

- The density of EPS shall not be less than 22 kg/m³.
- EPS blocks shall be fully wrapped with minimum 0.254 mm (10-mil) thick black polyethylene sheeting.
- Polyethylene sheeting joints shall be overlapped by a minimum of 0.5 m.
- EPS blocks shall have a minimum 1.2 m granular cover vertically and horizontally.

Shredded rubber tires or hog fuel (wood waste) shall not be used as fill.

Add the following clause:

6.19 Retaining Walls

Retaining wall types shall meet the durability requirements and aesthetic requirements specified for the project and shall be subject to the consent of the Ministry.

Design issues not addressed by S6-14 shall meet the requirements of AASHTO LRFD Bridge Design Specifications (7th Edition, 2014) including interim revisions.

Surface drainage and drainage of the backfill material shall be addressed in the design of the walls and details shall be shown on the Plans.

Walls with steel anchors, tie-backs, MSE soil reinforcing and/or soil nails, shall include additional full length anchors, tie-backs, soil reinforcing and/or soil nails installed in the walls to allow for future extraction for long term inspection and testing. The number of additional elements provided for each wall shall be equal to 2% of the number required by design but not less than 2 additional elements per wall.